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Role of Spatial Technologies in Ground Water Resource Augmentation: An Overview

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ABSTRACT: The last couple of decades have observed the development of remote sensing applied to various branches of geosciences. However, hydrogeologists have been comparatively slow to embrace satellite data as a tool in their work. Understanding the relationship between the surface and sub-surface environment has remained one of the key scientific issues in hydrogeology. Satellite based remote sensing gains importance towards hydrogeological research when physical models are used to "extrapolate" them in to the subsurface. Remotely sensed data like indigenous IRS-P6 LISSIVMX, IRS-P6 LISS-III, IRS-IC/ID LISS-III and PAN merged provide very useful baseline information on the parameters like geomorphology, lithology, lineaments, drainage network, paleochannels, weathered residuum, soils and land use/cover which are actually controlling the occurrence and movement of groundwater. Watershed which is considered as a hydrologic unit for ground water (in unconfined aquifer) development, can also be delineated by interpreting standard FCC data or through generation of digital elevation model (DEM). Soil moisture which is an indicator of sub surface water and evaporation loss can be traced by SMOS data. Fluctuation in water table condition can be detected by satellite-mapping the vegetation changes. Mapping of surface subsidence due to compaction of developed aquifer is done through interferometric synthetic aperture radar (InSAR) (Hoffman 2005).
Ground water development in fractured hard-rock aquifers like granite, granite-gneiss and basaltic lava flows or Decan traps, which occupy 67 percent of India, is less compared to that in the aquifers of unconsolidated sediments or in the soluble carbonate aquifers. The ratio of ground water recharge to rainfall in hard-rock terrain is customarily estimated between 9-13 percent (Limaye 2003). Efficient management of ground water is necessary in the above mentioned formation. Artificial recharge can augment ground water table condition where natural recharge is inadequate. The concept of integrating remote sensing and GIS is relatively new. GIS technique involves the integrated and conjunctive analysis of huge volumes of multidisciplinary data, both spatial and non-spatial, within the same geo-referencing scheme. Through integration of these two spatial data management technologies, ground water development through artificial recharge, exploring new aquifers, identification of fresh water aquifers in arsenic contaminated areas can be well organized. Overlay analysis involving several thematic layers like hydro geomorphology, lineament number density (isofracture) and drainage density in a GIS environment produces composite map(s) which ultimately reveals the desired locations. Intersection of moderate drainage density zone, high lineament number/intersection density zone and thick weathered residuum within a basin is potential for enhanced aquifer recharge. Paleochannels, weathered residuum and

alluvial fans are suitable for further progress of ground water exploration. GIS techniques have been applied on arsenic contaminated tube-well (in alluvial formation) data and paleochannel data for building up a spatial data base and also to create a probabilistic model for predicting spatial relationship between them. GIS modeling shows an optimum of 500m zone (buffer) of influence of paleochannels within which arsenic contaminated wells are likely to be encountered.
Keywords: ground water, remote sensing, GIS

Introduction:

This paper attempts towards an overview of the application of integrated remote sensing and geographical information system (GIS) in ground water studies. Ground water is restricted within subsurface. Satellite based remote sensing has no penetration capabilities beyond the upper most layer. Synergism of satellite remote sensing and GIS technique may be a useful asset in groundwater exploration and development. Satellite data interpretations involve use of surfacial indicators of the underlying groundwater reservoir and of course require considerable skill and knowledge in the part of the interpreter. Hydrologic applications of air photography was major field of interest in earth science research in the past (Ray 1960, Miller and Miller 1961).Satellite image interpretation towards geological application was effectively introduced by the work of Sabins (1987). However, the development of physiographical and geomorphological interpretation followed later. Visual interpretation of standard false color composite (FCC) data contains an optimal expression of terrain information. Indian national water policy lays down the desirability of integrated watershed-wise water management and land-use. For effective implementation, this has to be supported by detailed terrain evaluation. Government of India's planning commission's thrust on agro climatic zone based agricultural planning also needs to be integrated with terrain based development. Interpretative works on satellite imageries lead to mainly evaluation of the terrain condition. In this regard a comprehensive approach is needed which involves visual impression combined with ground truth data aiming towards achieving a continuous betterment.

Image Interpretation:

Analysis of drainage features, surface water bodies, physiography, structural lineaments, vegetation and 1and use which are most important for ground water are discernible in multi-spectral imageries of IRS and Landsat. Infrared bands yield most information on hydrogeology.

The main advantages in using remote sensing for ground water studies are:

1. Quick and inexpensive technique for getting first-level information on the occurrence of ground water.
2. Aids to select promising areas for more detailed hydrogeological/geophysical investigations, thus reducing fieldwork.
3. Provides better geologic and hydrologic information (particularly on a regional scale) because of synoptic, multi-spectral and multi-temporal character of the imagery.
4. Obtaining information over large areas about soil moisture and vegetation patterns. Often such information is indicator of occurrence of ground water at shallow depths.

Limitations of remote sensing in ground water development are:

1. Correlative quantitative estimates of expected yield in specific hydrogeological environments may be given very broadly from remotely sensed data.
2. Depth estimation of aquifers is very difficult.
3. Assessment of quality of water is difficult.

Hydrogeological/geomorphological evaluation:

The importance of satellite imagery in hydrogeological investigation is based on the principle, that, the multi-spectral images help the hydrogeologists in locating structural, morphological and vegetation features as possible keys that govern ground water flow in aquifers. The water on the surface, which has a bearing on ground water circulation subsurface, can be distinguished in the near infrared region owing to low reflection of water. Snow covered areas can easily be detected with sensors working in the visible and thermal infrared regions. The main objective of a hydrogelogical map is to present cartographically the hydrogeological properties of the mapping units in a systematic manner, with symbols added for hydrogeologic features(Meijerink 1996).Previous studies have shown how satellite imagery can contribute to the mapping and qualitative evaluation of a terrain(Jeyaram *et al*.1992;Waters *et* al.,1990).However, in many earlier works the Quaternary deposits were poorly differentiated on existing maps. This is regrettable because recharge, shallow flow systems and water quality are related to these often non- or little-consolidated deposits (Meijerink 1996).In order to assess groundwater resource potentiality or recharge potentiality, a number of related factors are to be evaluated from the imagery. Drainage texture or drainage density is very important in this regard. Information about lowest to highest order of drainage can easily be extracted from the data like IRS-P6 LISSIII, IRS-P6 LISSIVMX, IRS-IC/ID LISS-III and PAN merged. Wells located in highly permeable strata produce large quantities of water as infiltration from the streams makes up the ground water supply. Abandoned or buried channels are channels no longer occupied by stream that formed them. Intermontane valleys are underlain by large volume of unconsolidated rock materials derived by erosion of bordering mountains. The sand and gravel beds of these aquifers produce large quantities of water, most of which replenished by seepage from streams into alluvial fans at mouth of mountain canyon. Remote sensing techniques arc most useful in exploration of ground water covered by such deposits. Geo1ogical structures which contro1 ground water occurrence and movement are, bedding, fractures, joints, faults etc. Especially in hard rock terrain the structures are the major elements for the development of secondary porosity and permeabi1ity which in terms determine the aquifer characteristics.

Lineaments are defined as mapable linear surface features, which differ distinctly from the patterns of adjacent features and presumably reflect subsurface phenomena (O'Leary *et al*., 1976). One of the major contributions of the satellite imagery has been in the recognition of linear features varying in length from a few meters to hundred of kilometers. Such features are generally manifested as a variety of surface features including slight tonal differences in areas of rock outcrop, soil or vegetation cover alignment, topographic forms and drainage pattern. The linear features are generally related to faults, joints or fractures. Minor lineaments such as small scale faults and joints are also visible in the imagery. Often circular geologic anomalies are also identifiable.

Along with lithology and structure the landforms of an area also exercise tremendous control over the ground water. The scale corrected imagery act as a better database. The shape, size and materials of the various landforms in the alluvial, aeolian, deltaic, karstic and glacial regions determine the ground water potential. In hard rock areas the individual landform characteristics like depth of weathering and nature of weathered material determine the shallow aquifers.

IRS P6 LISSIII (Fig.1) and LISSIVMX (Fig.2) imageries provide better analysis for geomorphic study. In alluvial terrain buried/abandoned channel, alluvial fans, valley fills, meander scars etc., which are the suitable sites for ground water occurrence, can be mapped easily from IRSIC/ID LISSIII PAN merged data(Fig.3). In hard rock terrain mapping of pediment and buried pediment gives indication for ground water occurrences. Slope steepness is critical to water's infiltration quantity or water's run-off quantity. Infiltration capability highly depends on slope gradient, since, when slope increases, more water flows superficially and less infiltrates (regardless the lithological formation) (Leonidopoulou *et. al* 2008).Slope map is very much useful in this regard. DEM of a basin shows its boundary as well as it also the generalized 3-dimensional terrain features(Fig.4).

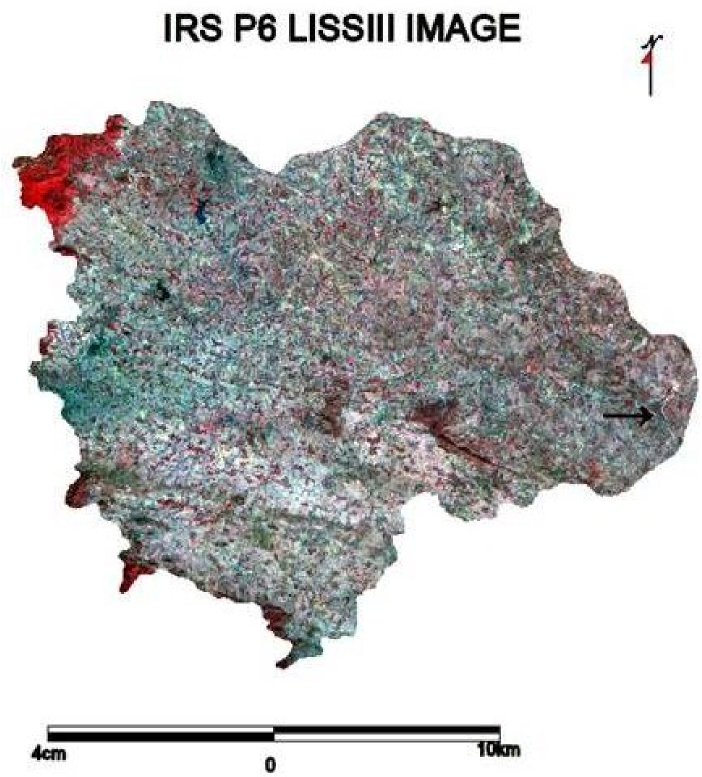

Figure 1. Image shows a watershed

Figure 2. Image shows upper catchment area of a watershed

Land subsidence can result from irreversible compaction of low permeability materials in or adjacent to the developed aquifer as fluid pressure declines because of ground water withdrawals. Extensive subsidence has been well documented on Mexico City, Bangkok, Sanghai and elsewhere (Konikow and Kendy 2005).Detection of land subsidence is done through interferometric synthetic aperture radar (InSAR).The measurements of soil moisture from satellites has received much attention in the recent days. The Soil Moisture and Ocean salinity (SMOS) mission of the European Space Agency(ESA) employed imaging radiometer is capable to measure the surface brightness temperature. This temperature can be used to estimate soil moisture from most surfaces (Hoffman 2005).

Figure 3. IRSIC/ID LISSIII PAN merged geocoded data show abandoned channel and meander scars

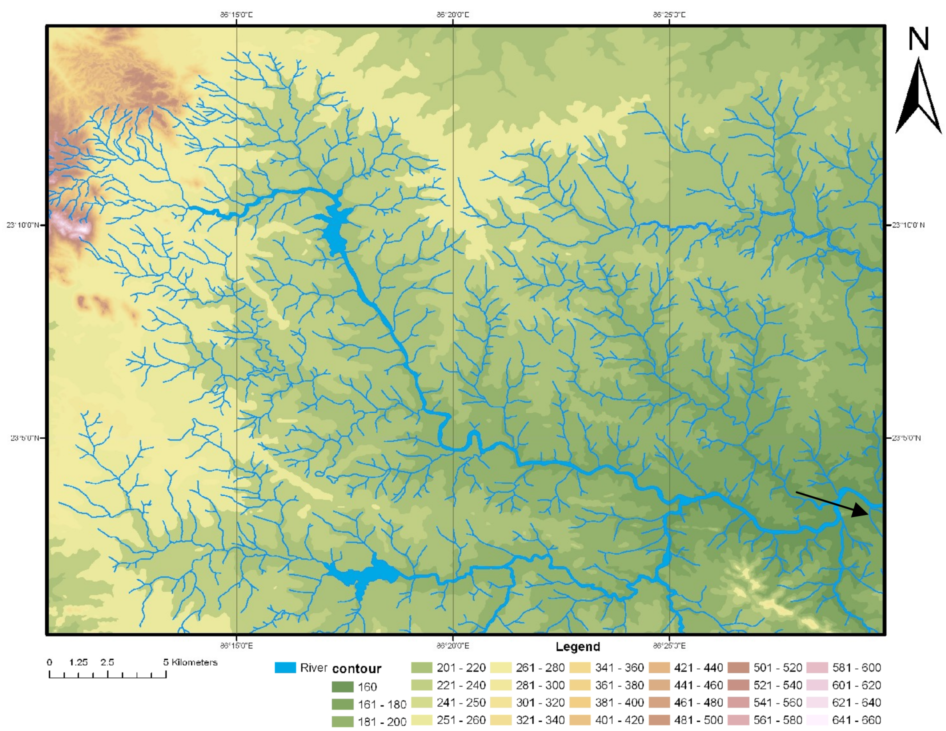

Figure 4.Drainage is draped on DEM of a watershed (after Das 2011)

Approaches in GIS analysis for artificial recharge of aquifer and arsenic contaminated ground water studies:

In the recent years it has been observed that a sharp decline in water table condition has taken place due to over withdrawal of ground water. This is mainly due to the agricultural revolution in which thousands of small farmers developed their own sources of irrigation using ground water wells. Moreover, the problem of natural recharge due to presence of hard crystalline rock, undulatory terrain condition and vagaries of monsoon is already present in our country and many parts of the world as well. So, the necessity of artificial recharge of potential aquifers has become inevitable. Weathered fraction of hard-rock and paleochannels offer a limited source of fresh water for irrigation and drinking water supply. Spatially extent weathered residuum and paleochannels are clearly discernible in satellite imageries. Pertinent thematic layers are created using satellite data aided by field verification aiming towards overlay analysis in a GIS environment. The role of GIS analysis (overlay analysis) for artificial recharge site selection have been proved to be very effective. Composite map (Fig.5)shows suitable sites for artificial recharge of potential aquifers in a hard-rock terrain(Fig.5).

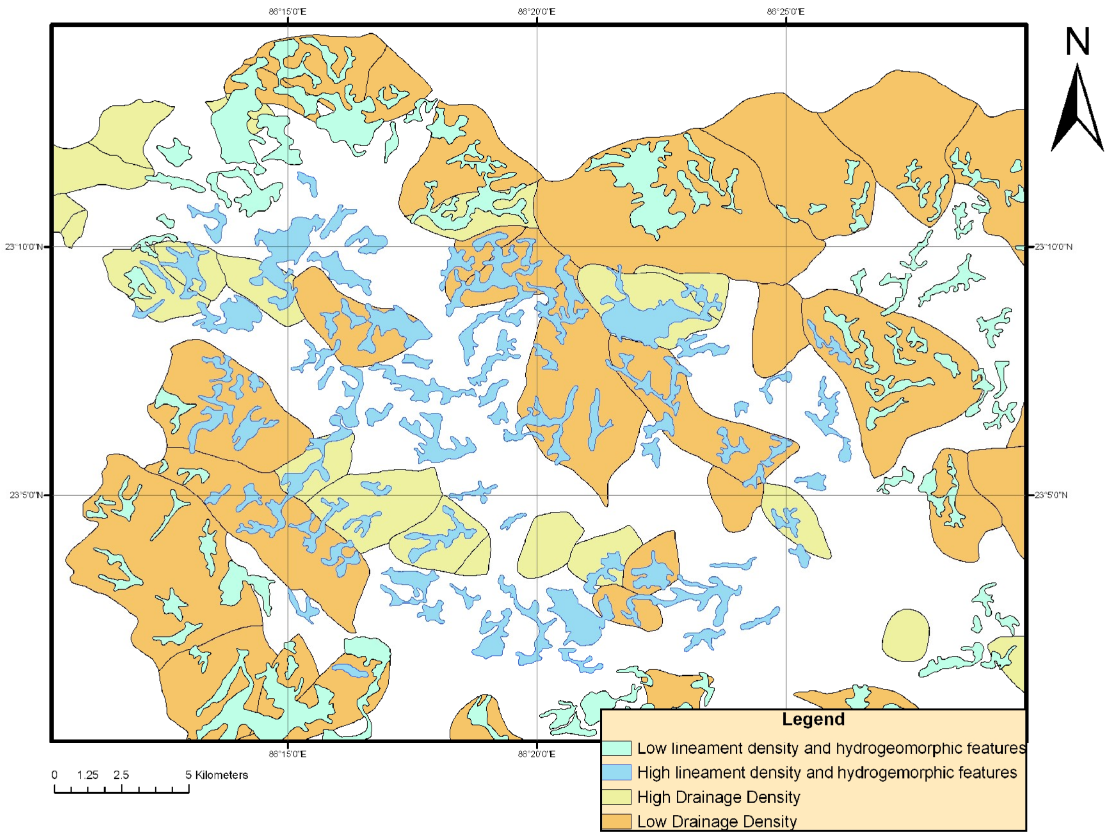

Figure 5. Sites for artificial recharge (blue colored small polygons within yellow colored polygon)

(after Das 2011)

Arsenic contamination in groundwater beyond the permissible limit of 0.05 mg/l has been found to be present in the shallow aquifer (20–150 m bgl) located in the part of Bengal delta, covering the southern portion of West Bengal state of India and Bangladesh. The higher concentration of arsenic is restricted mainly the upper delta plain within older (abandoned) exposed meander belt. In case of arsenic contaminated ground water studies, the thematic maps generated from both SOI topographic maps and IRS 1D satellite data (Fig.6) were imported, geo-referenced and digitized under GIS environment. The composite image generated through the combination of spectral bands 2,3& 4 was georeferenced by co-registering the selected ground control points that are prominently identifiable, both from the image as well as the topographic maps of the area on 1:50,000 scale. Visual interpretation technique was followed for preparing geomorphological map of the study area. Image interpretation keys, such as tone, texture, size shape, pattern and association were taken in to consideration to delineate various landform elements and geological units. The false color composite (FCC) image clearly shows the areas with vegetation /crops, (deep vegetation as deep red and scattered vegetation as light red) (Fig.6).The water bodies are endowed with black or dark grey color whereas dry stream or unclassified palaeochannels exhibit a grey tone. Band 4 of IRS 1D belonging to near infrared part of the electromagnetic spectrum shows the high moisture areas in dark tone. As such IRS 1D FCC in band 2, 3 and 4 permit picking up the palaeochannels, meander scar, swamp and back swamp quite successfully. The waterlogged areas show the light dark grey to black color. Interpreted palaeochannels have been picked out and incorporated in GIS as line coverage. The water bodies, meander-cut, ox-bow lake, abandoned channels and land use pattern also incorporated in GIS as polygon coverage and arsenic contaminated/non-contaminated well are as point coverage. GIS tools on arsenic contaminated tube-well data and palaeochannel data have been utilized for building spatial database and also to create probabilistic model for predicting spatial relationship between them(Fig.7).A composite geomorphological map has been generated to show the distribution of arsenic contaminated and non-contaminated tube-wells(Fig.8).

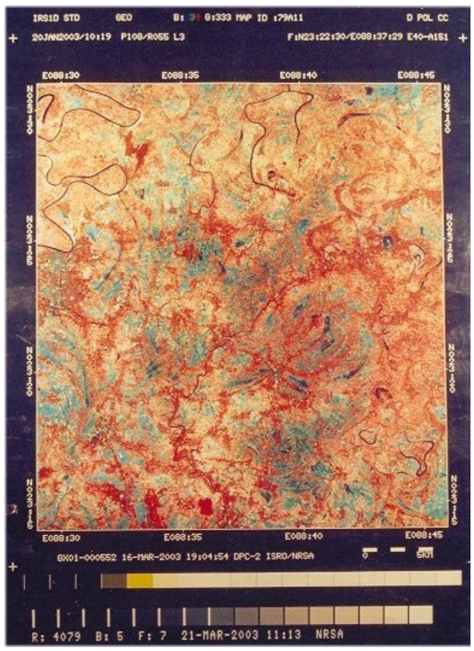

Figure 6. IRS ID data show vegetation /crops, palaeochannels and meander scar

All digitally enhanced and edge extracted images were used to identify and digitize geomorphic elements which were overlaid to obtain the composite geomorphological map of the region (fig. 8).

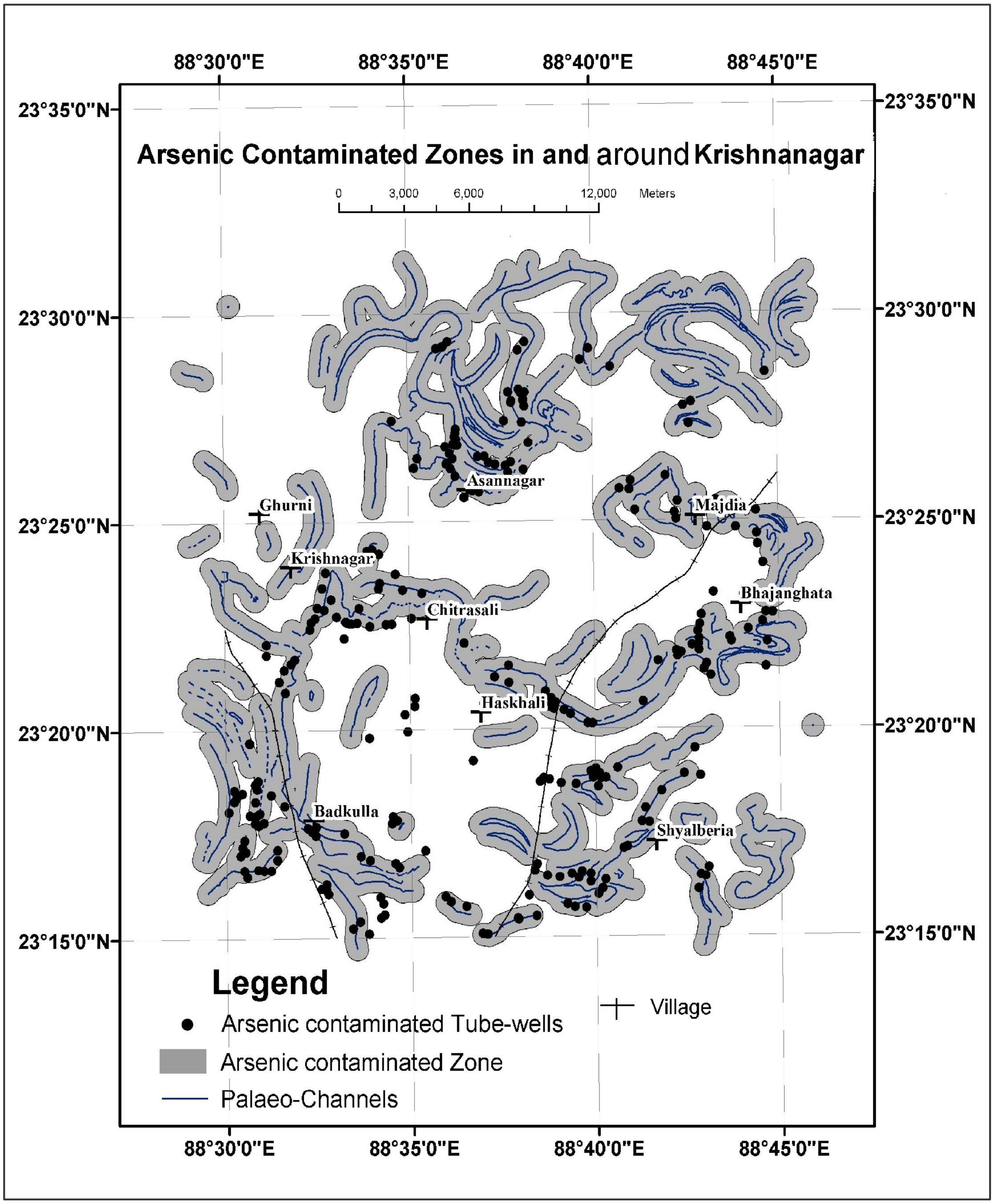

Figure.7 Distribution of arsenic contaminated wells within the palaeochannel corridors (after Mukherji 2007).

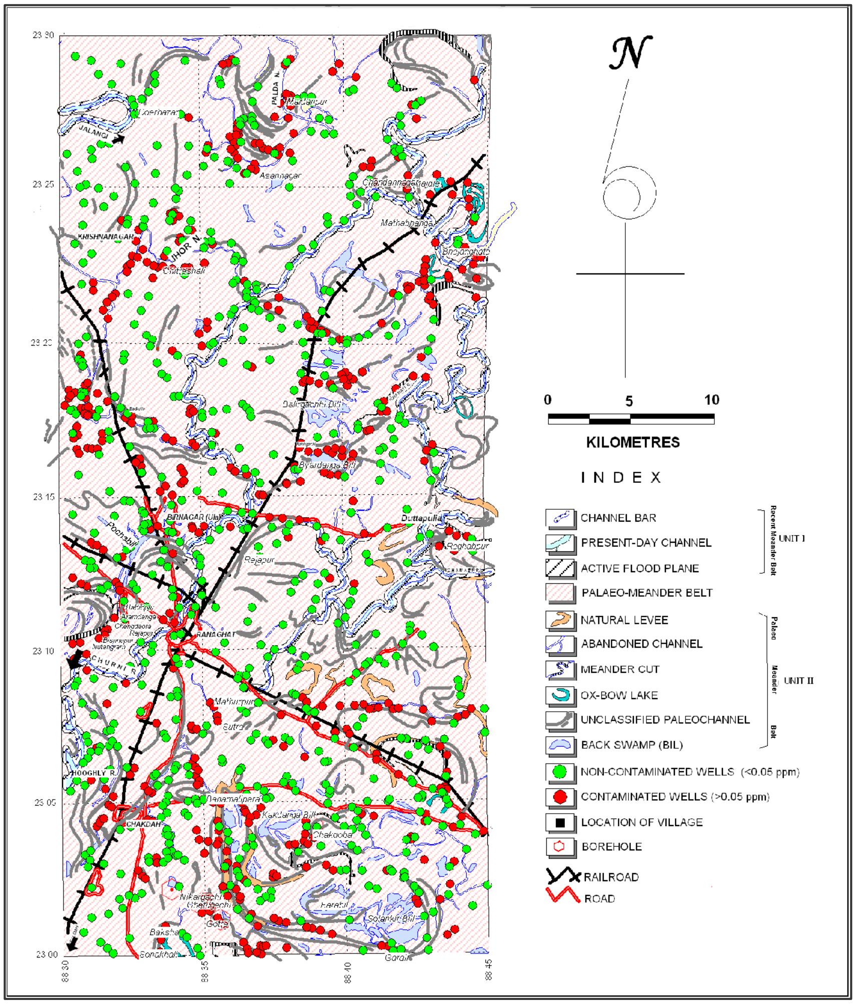

Figure.8 Final composite geomorphological map of study area. (after Mukherji 2007)

Discussion:

Spatial technologies provide unique and unbiased input in ground water resource inventory program. Integrated approach of satellite based remote sensing and GIS provides a responsible sense of application towards the appraisal of geological, geomorphological, lineament factors which control occurrence and movement of groundwater of a region. Since surface drainage and its hydrological characteristics provide important clues towards ground water resource, their appropriate characterization can also be accomplished through the integrated approach of remote sensing and GIS techniques. Changes in land cover/land use through time and its detection using satellite sensing provides valuable information regarding changes in hydrological regime. Watershed analysis provides a framework for ecosystem management, which is currently the best option for conservation and management of natural resources as well. Clear detection of watershed boundary and lowest to highest order drainage using satellite data helps to develop a faithful quantitative data base on the aerial aspects of drainage basins which in turn provides a clue towards surface run-off and ground water recharge status. Changes in wet land condition and soil moisture can easily be detected by satellite data and which can assess the fluctuation in water table condition. Both toposheet and satellite derived DEMs have dramatically improved the availability, accuracy and detailed topographic information.

Conclusion:

Historically, human society responses to drought by impounding surface run-off to develop fresh water reservoirs. People search for fresh water when surface or ground water becomes contaminated. However, there is always a dearth of geologically/geomorphologically suitable locations for construction of water harvesting and artificial recharge structures. Exploration of virgin areas for fresh water availability is not an easy task. The synergism between remote sensing and GIS has been proved to be a blessing in ground water resource augmentation.

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